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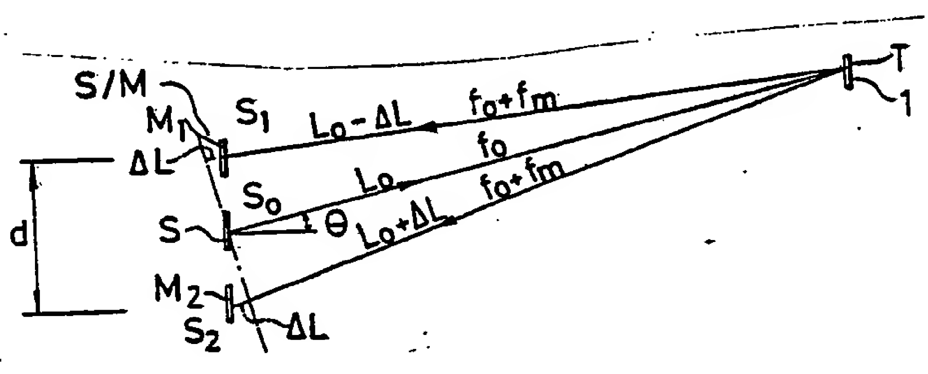

(57) Abstract

A method for determining a mutual position between two objects, comprising transmitting a microwave signal from the first object towards the second object, causing the second object to receive the transmittal signal and re-transmit a signal, which is caused to be received by the first object. According to the invention the first object includes a transmitter/receiver unit (S/M-unit), which transmits the aforesaid signal (f_o) from a transmitter antenna. The second object (T) is caused to re-transmit the aforesaid signal modulated with a signal (f_m), the first object being caused to receive the transmitted signal through at least two antennae (M_1, M_2) placed symmetrically on a respective side of the transmitter antenna (S) and in an antenna plane common with the transmitter antenna (S). The angle (θ) between the antenna plane and the second object, at least in one dimension, is determined by a phase comparison or an amplitude comparison of received signals, in dependance on whether or not the second object (T) is located in the so-called proximity zone of the first object. The invention also relates to apparatus for carrying out the method.

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A method for position-finding and apparatus herefor.

The present invention relates to a method for determining a mutual position between two objects, and apparatus herefor.

A need for measuring the mutual positions between two objects is to be found in a number of industrial applications and other forms of application, such as the relative positions of a movable and a stationary object. One applicable example is that of a robot adapted to seek automatically an object in order to carry out work thereon. If the position of the robot relative to the object is unknown, it is necessary to use a position meter in order to first determine the position of the robot in relation to the object. Another example is that of determining the position of equipment, such as machines, in relation to the surroundings, for example different ground reference points.

The present invention is particularly suitable for determining the mutual positions of two objects in relation to one another in those cases where a first object is intended to seek a second object. It will be understood, however, that the present invention can be applied on all occasions where there is a need of determining the relative positions of two objects.

The present invention relates to a method for determining a mutual position between two objects, which comprises transmitting a microwave signal from the first object to the second object; causing the second object to receive the signal and to re-transmit a signal which is received by the first object, and which method is characterized in that the first object incorporates a transmitter/receiver which is caused to transmit said signal from a transmitter antenna at a frequency f_o; in that the second object is caused to re-transmit said signal modulated with a signal f_m; in that the first object is caused to receive the re-transmitted signal on at least two antennae placed symmetrically on a respective side of the transmitter antenna in an antenna-

plane common with said transmitter antenna; and in that the angle between said antenna-plane and said second object in at least one dimension, namely in a first plane passing through the transmitter antenna and the two receiver antennae, is determined by respectively a phase comparison and an amplitude comparison of received signals, depending upon whether the second object is located in the so-called proximity zone of the first object or not, i.e. located at a distance which is shorter, or not, than a distance of the same order of magnitude as the distance d between said two receiver antennae, wherein when the second object is located outside said proximity zone said angle is determined by a phase comparison between the signal received by respective antennae subsequent to being mixed with the transmitter signal f_o, where the phase difference between the signals is determined; and in that said angle is determined with the aid of a computer device associated with the transmitter/receiver unit from the relationship

$$\theta = \arcsin \left[\frac{(F_2 - F_1) \cdot C}{2\pi \cdot f_o \cdot d} \right]$$

where c is the speed of light and d is the distance between the two receiver antennae.

The invention also relates to apparatus of the kind set forth in Claim 6 and having the fundamental characteristics disclosed therein.

It is possible when using the method and apparatus according to the invention to determine the direction in which a reference point lies in relation to a transmitter/receiver unit, referred to as the S/M-unit. The reference point is a transponder T.

The values are determined in accordance with the invention with the use of microwaves. By using microwaves instead of optical systems, for example, there is obtained a system which will not be influenced by a troublesome environment, such as an environment which incorporates dust,

dirt, light-reflections etc.. This has an important significance in industrial applications.

A particular problem arises when the transponder lies close to the S/M-unit, or more precisely within the so-called proximity zone of the S/M-unit.

This problem is resolved in that the S/M-unit switches from a mode in which the difference in phase between received microwave signals is measured to a mode in which the amplitude of said signals is measured. This is a highly significant contribution to the art of position finding by phase measurement, since by utilizing an amplitude measuring technique it is possible to lead an object, such as a robot, right up to the target object.

The invention will now be described in more detail with reference to a number of exemplary embodiments thereof and to explanatory diagrams illustrated in the accompanying drawings, where

Figure 1 illustrates the principle of angular measurement;

Figure 2 is a block schematic illustrating a transmitter/receiver unit for phase measurement;

Figures 3 and 4 illustrate two mutually different embodiment with alternative positioning of the antennae of the transmitter/receiver unit;

Figure 5 illustrates schematically the principle propagation of the so-called proximity zone;

Figure 6 is a block schematic of a transmitter/receiver unit for amplitude measurement;

Figure 7 is a diagram in which the amplitude of the received signal is shown as a function of the position of the receiver antennae;

Figure 8 is a diagram in which the amplitude of the received signal is shown as a function of the distance between transponder and the receiver antennae;

Figure 9 illustrates a further alternative in the positioning of the antennae of the transmitter/receiver unit;

Figure 10 is a block schematic of a transmitter/receiver unit for both phase and amplitude measurement; and

Figures 11 and 12 illustrate examples of the manner in which the invention can be applied.

Fig. 1 illustrates the principle of angular measurement in a single plane. The transmitter/receiver unit S/M has located in said plane two receiver antennae M_1, M_2, and a transmitter antenna S. The transponder T includes a receiver antenna and a transmitter antenna, both of which are preferably combined in a transponder antenna 1. The transmitter/receiver unit, referred to as the S/M-unit, is adapted to transmit a microwave signal having a frequency, for example, of f_o = 2450 MHz. As explained in more detail hereinafter, the transponder is adapted to receive the signal f_o and to re-transmit a signal $f_o + f_m$, where f_m is, for example, 10 kHz, i.e. to reflect the signal f_o transmitted by the S/M-unit.

The reflected signal is received by the receiver antennae M_1, M_2, which are symmetrically positioned at a given mutual distance apart on a respective side of the transmitter antenna S. Because of the difference in the distance travelled by the reflected and received signals $f_o + f_m$, there is a difference in the phases of the signals received on the antennae M_1, M_2 corresponding to the difference in the aforesaid distances. The signal received on the antenna M_1 has travelled the distance $2L_o - \Delta L$ where L_o is the distance from the transmitter antenna S and the transponder antenna 1. The signal received on the antenna M_2 has travelled the distance $2L_o + \Delta L$. The signals S_1 on the anntenna M_1, S_2 on the antenna M_2 and S_o on the transmitter antenna can be described in accordance with the relationships

$$S_o = \cos\ (2\pi \cdot f_o \cdot t) \qquad (1)$$

$$S_1 = k_1 \cdot \cos \left[2\pi\ (f_o + f_m)\ (t - \frac{2L_o - \Delta L}{c}) \right] \qquad (2)$$

$$S_2 = k_2 \cdot \cos \left[2\pi\, (f_o + f_m)\, (t - \frac{2L_o + \Delta L}{c})\right] \qquad (3)$$

where k_1 and k_2 are constants and $\underline{c}$ is the speed of light.

The S/M-unit is illustrated schematically in Fig. 2. The reference 2 identifies a local oscillator adapted to generate a signal having the frequency f_o, this signal being passed to the transmitter antenna S, and to each of two homodyne mixers 3,4. The second input of the mixer 3 is connected to the one receiver antenna M_1, while the second input of the other mixer 4 is connected to the other receiver antenna M_2. The prevailing frequences are given in Fig. 2.

Subsequent to homodyne mixing of the signal in the mixer 3,4 there are obtained the signals S_1' and S_2' respectively according to the equations

$$S_1' = k_3 \cdot \cos\, (2\pi \cdot f_m \cdot t + \phi_1) \qquad (4)$$

$$S_2' = k_4 \cdot \cos\, (2\pi \cdot f_m \cdot t + \phi_2) \qquad (5)$$

where $\phi_1 = \dfrac{2\pi \cdot f_o}{c} (2L_o - \Delta L)$ and (6)

$$\phi_2 = \frac{2\pi \cdot f_o}{c} (2L_o + \Delta L) \text{ and} \qquad (7)$$

where k_3 and k_4 are constants.

The phase difference between S_1' and S_2' is given by

$$\phi_3 = \phi_1 - \phi_2 = \frac{2\pi \cdot f_o}{c} \cdot 2 \cdot \Delta L \qquad (8)$$

The angle θ between the antenna plane of the S/M-unit and the transponder T, c.f. Fig. 1, can be expressed

$$\theta = \arcsin\, (\frac{2\Delta L}{d}) \qquad (9)$$

where $\underline{d}$ is the distance between the two receiver antennae M_1, M_2.

From the equations there is obtained

$$\theta = \arcsin\left(\frac{\phi_3 \cdot c}{2\pi f_o \cdot d}\right) \qquad (10)$$

Thus, by measuring the phase difference ϕ_3 it is possible to measure the angle θ between the S/M-unit and the transponder T through the intermediate frequency f_m obtained with said homodyne mixing of the signal, and the phase measurement can be effected at a low frequency instead of at a microwave frequency.

The afore-description related to measurement in a single plane, i.e. in one dimension. By providing a further two receiver antennae M_3, M_4 in a second plane at right angles to the first plane in which the receiver antennae M_1, M_2 are located, and by placing these further receiver units M_3, M_4 in a corresponding manner on both sides of the transmitter antenna S, and by providing a further two mixers, it is possible to determine an angle θ' between the S/M-unit and the transponder in said second plane, wherewith the angular position of the transponder T in relation to the S/M-unit is determined in two mutually perpendicular planes.

The accuracy at which the angles θ, θ' can be determined increases with increasing distance d. On the other hand the angle of maximum clarity is decreased herewith. In order to obtain non-ambiguity or clarity within the angular range $-45^o < \theta, \ \theta' < 45^o$ the distance d must be greater than $\lambda/\sqrt{2}$, where λ is the wavelength at the frequency f_o, where $-180^o < \phi_1, \phi_2 < +180^o$.

One method of increasing the accuracy while retaining a large angle of maximum clarity is to arrange further receiver antennae M_6, M_7 and M_8, M_9 respectively, see Fig. 4, externally of and in the same plane as the aforesaid receiver antennae M_1, M_2 and M_3, M_4 respectively.

The transponder T is preferably in the form of a so-called recording indicator of the kind descriped in Swedish Patent Specification No. 7503620-2. This recording

indicator comprises a transmitter antenna and a receiver antenna, which may comprise an antenna 1. Connected to the antenna is a simple sideband modulator 5. A pulsetrain generator 6 is arranged to generate a pulsetrain 7, preferably of individual appearance for each of the transponders in that case when a plurality of mutually different transponders T are provided, the pulsetrain being controlled by an oscillator 8. The frequency f_m generated by the oscillator 8 is applied to the modulator 5, for example when a pulse in the pulsetrain is delivered to the oscillator, since the oscillator will only generate the frequency f_m when one pulse is delivered. The signal supplied to the antenna 1 thus comprises a pulsetrain corresponding to the pulsetrain 7, comprising the frequencies. $f_o + f_m$, where the frequency f_o prevails between the pulses in the pulsetrain 7 and the frequency $f_o + f_m$ prevails during each pulse.

By making the pulsetrain 7 individual for each transponder T and by providing the S/M-unit with a decoder adapted to decode the pulsetrain for identification of the transponder T, the S/M-unit is able, where appropriate, to determined the angles Θ, Θ' of one transponder selected from a plurality of transponders.

This embodiment affords a particular advantage when the S/M-unit is used to guide a robot arm towards an object, where one of a plurality of transponders is selected in dependence on a desired robot operation, or where the robot arm is intended to seek a plurality of mutually different objects in a given order of progression.

This latter description relates to determining the position of a transponder in relation to the S/M-unit in two dimensions. In the case of practical applications, however, it is necessary in certain instances to also measure the mutual position in the third dimension.

It is certainly sufficient in many cases to measure in two dimensions.When the invention is applied to a robot, the robot can be so constructed that, on the basis of a

measurement of θ, θ', the arm of said robot is moved in the direction given by said angles, and if necessary to carry out a plurality of measurements during movement of the robot arm until indication is obtained through a suitable device that the robot arm has reached its target.

It is often necessary, however, to obtain information concerning the distance to the object, particularly when the robot arm approaches said object more closely. Thus, it is desirable to obtain such information in the so-called proximity zone, indicated by the shaded area in Fig. 5, i.e. when the S/M-unit and the transponder T are in close proximity of one another. In the proximity zone the distance between the objects is of the same order of magnitude as the distance $\underline{d}$. More specifically, the proximity zone extends outwardly from the S/M-unit to an extent corresponding to $1.5 \cdot d$ and has a width equal to $\underline{d}$. It is of primary importance to be able to detect with high precision when the transmitter antenna of the S/M-unit lies centrally of the transponder antenna.

In accordance with a preferred and highly important embodiment of the present invention, the amplitude of the signals received by the S/M-unit is measured instead of the phase differences of said signals, in order to determine the position of the S/M-unit in the proximity zone three-dimensionally. There is used in this embodiment of the invention an arrangement schematically illustrated in Figs. 6 and 9, this arrangement having the same principle construction as the arrangement illustrated in Fig. 2, but with the difference that the signal received by each of the receiver antennae M_1, M_2, M_5 is mixed with the frequency f_o generated by the oscillator 12 in mixers 9,10,11, wherewith three signals S_1', S_2', and S_5' corresponding to the equations (4) and (5) above are produced. Thus, the transmitter antenna S also forms a receiver antenna M_5, see Fig. 9. The embodiment of Fig. 9 also incorporates two further antennae M_3 and M_4, analogous with the antenna array illustrated in Fig. 3, to enable measurement to be effected in two mutually

perpendicular planes. One further difference is that the mixers 9,10,11 are provided with a respective output for a signal G_1, G_2 and G_5 corresponding to the amplitude of the signal received from the antennae M_1, M_2 and M_5 respectively.

In Fig. 7 the measured amplitues G_1, G_2 and G_5 are illustrated as a function of the position of the transponder T when its antenna is displaced laterally in relation to the antennae of the S/M-unit. The perpendicular distance between the antenna of the transponder T and the antennae of the S/M-unit is thus constant.

When the transponder T lies centrally of the transmitter antenna S the ratio of $G_1/G_2 = 1$ (0 dB). When the transponder lies to the left of the antenna S, $G_1/G_2 > 1$, while when it lies to the right of said antenna $G_1/G_2 < 1$. In the proximity zone the logarithm of the quotient G_1/G_2 is proportional to the distance X, which indicates lateral displacement. The quotient G_1/G_2 is also proportional to the angles θ, θ'.

Thus, it is possible with the aid of the logarithm of the quotient G_1/G_2 to determine lateral displacement of the transponder antenna in the plane relative to the transmitter antenna S/M-unit.

By using three receivers M_1, M_2, M_5, as described above, it is also possible to determine the magnitude R in accordance with the expression (11) and also the distance Z between the S/M-unit and the transponder. The distance Z is namely an unequivocal function of the quotient

$$R = \frac{G_5}{\sqrt{G_1/G_2}} \qquad (11)$$

Fig. 8 illustrates the amplitude G_5, the quotient G_1/G_2 and the quotient R as a function of the distance between the transponder antenna 1 and the transmitter antenna S when said antennae lie centrally opposite one another.

The function Z = F (R) can be approximated with a polynomial function. The appearance of the function is

determined, inter alia, by the geometry of the antenna arrangement and the frequency.

Thus, when the transponder is located in the proximity zone, both direction and distance to the transponder can be determined.

In accordance with a preferred embodiment of the invention, the S/M-unit switches from a mode in which the angles Θ, Θ' are determined to a mode in which phase differences are determined, in order to determine distance and angles to the transponder in accordance with the embodiment just described, when the transponder enters the proximity zone. Preferred conditions for transition from a so-called remote mode to a so-called proximity mode are given hereinafter, where the invention is further described with reference to an embodiment concerning measurement in two mutually perpendicular planes.

Fig. 10 illustrates one embodiment of such an arrangement according to the invention. This embodiment is in principle structurally similar to that described above. A microwave oscillator 13 generates a signal of frequency f_o, for example, a frequency of 2450 MHz. The signal is divided into six equal parts through a power divider 14, a directional coupling 15 and a power divider 16, such as to transmit the divided signal to the transmitter antenna 5, to one of the inputs of each of five respective mixers 17,18,19, 20,21, the other input of which is connected to respective receiver antennae M_1, M_2, M_3, M_4 and M_5. The antenna M_5 is connected to the other input of the mixer 21 through the directional coupling 15. Thus, the transmitter antenna S transmits the frequency f_o. The transponder is arranged to receive the signal and to re-transmit a signal having the frequency $f_o + f_m$, where f_m may be 10 kHz. The signal $f_o + f_m$ received by each of the receiver antennae is passed to respective mixers 17-21, where the signals are mixed down to the frequency f_m, said signals being amplified in amplifiers 22,23,24,25,26 connected to the output of respective mixers. Each of the amplifiers 22-26 is connected to

a respective rectifier 26,27,28,29,30.

The signals $S_1' - S_4'$ obtained subsequent to mixing of the signal $f_o + f_m$ have the same mutual phase and amplitude relationships as those prevailing between the signals $S_1 - S_5$, prior to said mixing. Subsequent to said mixing process, the signals are amplified and band-pass filtered in said amplifiers 22-26.

A signal $G_1 - G_5$ corresponding to the amplitude of respective signals $S_1 - S_5$ appears on the output of respective rectifiers 26-30. These signals are passed to a respective input of a computer unit 31.

Phase measurement is effected by four phase meters 32,33,34,35 arranged to measure the phase difference between respective received signals $S_1' - S_4'$ and a reference phase given by the signal S_5'.

The signal S_5' is delivered to one input of each of the phase meters, while each of the signals $S_1' - S_4'$, subsequent to amplification in the amplifiers 22-25, is delivered to the second input of the phase meters.

A signal $F_1 - F_4$ corresponding to respective phase differences occurs on the outputs of respective phase meters 32-35. These signals are passed to a respective input of the computer unit 31.

The computer unit is arranged to calculate the angle Θ between the S/M-unit and the transponder in partly two mutually perpendicular planes, for example the vertical plane (Θ_V) and the horizontal plane Θ_H) in accordance with the relationships

$$\Theta_H = \arcsin \left[\frac{(F_2 - F_1) \cdot c}{2\pi \cdot f_o \cdot d} \right] \qquad (12)$$

$$\Theta_V = \arcsin \left[\frac{(F_4 - F_3) \cdot c}{2\pi \cdot f_o \cdot d} \right] \qquad (13)$$

where the antenna array is that illustrated in Fig. 9 and where the distance d is the distance between the antennae M_1 and M_2 and the antennae M_3 and M_4 respectively, illustrated in Fig. 1.

The computer unit 31 is also arranged to calculate whether or not the transponder is located in the proximity zone, and to carry out calculations in accordance with the expression

$$\log \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}} < k_5 \qquad (14)$$

and

$$k_6 \cdot G_5 < \max (G_1, G_2, G_3, G_4) \qquad (15)$$

where k_5 and k_6 are constants chosen so as to be pre-determined when undertaking respective calculations.

The left side of the expression (14) corresponds to the equation (11), but for two mutually perpendicular planes.

The right side of the expression (15) shall be read as the highest of the values G_1, G_2, G_3 and G_4.

In a corresponding manner, the following expressions apply for determining the proximity zone in one dimension, these expressions corresponding totally to the expressions (14) and (15) for two dimensions, namely

$$\log \frac{G_5}{(G_1 \cdot G_3)^{1/2}} < k_{10} \qquad (16)$$

and

$$k_{11} \cdot G_5 < \max (G_1, G_2) \qquad (17)$$

where k_{10} and k_{11} are constants.

Thus, the magnitude of the proximity zone is determined by selection of the values of respective constants k_5 and k_6. In order to obtain a well-defined limit in respect of the proximity zone, the constants should be chosen so that the proximity zone obtains an extension similar to that illustrated in Fig. 5, or somewhat smaller.

The remote zone is defined by fulfilling one of the expressions (14) or (15). Thus, when one or the other of

the expressions (14) or (15) is fulfilled, the computer unit 31 is programmed to determine the angular position between the S/M-unit and the transponder, by calculating the angles Θ_V and Θ_H in accordance with the equations (12) and (13).

When none of the conditions is fulfilled, the computer unit 31 is programmed to switch to a mode for calculating the angles Θ_H and Θ_V according to the equations:

$$\Theta_H = k_7 \cdot \log\left(\frac{G_2}{G_1}\right) \tag{18}$$

$$\Theta_V = k_8 \cdot \log\left(\frac{G_3}{G_4}\right) \tag{19}$$

where k_7 and k_8 are constants, i.e. in accordance with the aforegoing, and is programmed to determine the magnitude R in accordance with the equation

$$R = \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}} \tag{20}$$

i.e. in accordance with the principle aforedescribed with reference to the equation (11).

In a corresponding manner, determination of the magnitude R in one dimension is effected with the aid of the equation

$$R = \frac{G_5}{(G_1 \cdot G_2)^{1/2}}$$

As will be seen from the aforegoing, inter alia from the description made with reference to Fig. 8, the magnitude R constitutes a measurement of the distance between the first object (S/M) and the second object (T).

In certain applications it is desirable to cause, for example, the S/M-unit carrier, such as a robot, to seek and to move towards the transponder. Thus, in this case it is necessary to be informed when the transponder is located in

the proximity zone of the S/M-unit. In addition, it is often desirable to stop the robot when the S/M-unit is located at a given distance from the transponder. This pre-determined distance is given unequivocably by a given value of the magnitude R. Such pre-determined values are determined empirically and stored in a memory associated with the computer unit.

However, it is also desirable at times to obtain information relating to the prevailing distance between the S/M-unit and the transponder when the transponder is located in the proximity zone.

In cases such as these, the aforegiven functional relationship $Z = F(R)$ is determined empirically. The relationship can be stored as a series of R-values coupled to corresponding Z-values. However, the series of empirically determined measurement values can be given an analytical expression by assigning a polynomial function or a logarithmic (log) function in a conventional manner, and determining its constants with the aid of the empirically determined values. In this respect, the least square error method can be applied for example.

The thus determined analytical expression $Z = F(R)$ is introduced into the computer unit, said unit being programmed to insert the calculated magnitude R into the expression $Z = F(R)$ and therewith determine the absolute distance Z.

The computer unit 31 is provided with outputs on which the unit is arranged to provide signals corresponding angle Θ_H and the angle Θ_V and the magnitude R and optionally the distance Z (dist). There may also be provided an output which produces a signal (F/N) indicating whether the computer unit operates in its proximity mode or its remote mode. These signals can be applied to, for example, a control and regulating unit for, for example, a robot, or to some other unit where the signals are utilized.

One of a particularly large number of the uses to which the present invention can be put will now be described

with reference to Figs. 11 and 12. The illustrated application relates to the automatic filling of vehicle gasoline tanks.

The illustrated embodiment includes a fuel pump 50 provided with a telescopically extensible robot arm 51. The robot arm 51 is mounted concentrically on a first rotatable plate 52, which in turn is mounted concentrically on a second rotatable plate 53, the diameter of which is approximately twice that of the firstmentioned plate. By rotating both plates 52, 53, the robot arm is able to reach a region in the vertical plane, which is corresponded by the larger plate 53. Attached to the free end of the robot arm 51 is a robot head 54 which incorporates a tube having a withdrawable and retractable hose 55 connected to the fuel tank of the fuel pump 50, an S/M-unit 56 of the aforedescribed kind and a mechanical means 57 for opening the fuel-filling line of an automobile.

Fig. 12 illustrates the fuel-filling location of an automobile. To this end, said location includes a cover plate 58 which can be opened automatically or from the driver's seat, a fuel-filling line 59 and a mechanical means 60 for opening said line, and a transponder 61.

When the automotive vehicle is placed within the working range of the robot and the cover plate 58 is opened, the S/M-unit detects the presence of the transponder 61. A robot regulating and control unit for the robot is activated by a microdata processor to which the computer unit 31 is connected. The control and regulating unit then moves the robot head towards the fuel-filling location 62, until the transponder 61 is located in the proximity zone. This is effected by rotating the plates to the necessary extent and by telescopically extending the robot arm with the aid of suitable drive means. The computer unit successively controls the aforesaid criteria relating to the proximity zone. When the transponder is located in the proximity zone, the computer unit 31 switches to said proximity mode, and thus guides the antennae of the S/M-unit onto the antenna of

the transponder, via the microdata processor and the control and regulating unit, until the transponder is located at a pre-determined distance from the robot head, wherewith the mechanical members 57,60 are in contact with one another. The robot-head member may, for example, have the form of a motor-driven gear ring which co-acts with the other mechanical member 60, which may also have the form of a gear ring, in a manner to open the fuel-filling line 59 of the automotive vehicle in a suitable manner. The hose 55 is then located in said direction of alingment at the mouth of the line or ducting 59. The hose 55 is then inserted through a short distance into the line or ducting 59, whereafter a given quantity of fuel is dispensed.

Subsequent to dispensing the aforesaid given quantity of fuel, the hose 55 is retracted into the robot arm 51, the fuel-filling line 59 is closed by the members 57,60, and the robot head returns to its starting position close to the fuel pump 50.

Although the invention has been described with reference to a robot by way of example, it will be understood that the invention embraces any suitable application.

The invention is not restricted to the aforedescribed embodiments and modifications can be made within the scope of the following claims.

CLAIMS

1. A method for determining a mutual position between two objects, comprising transmitting a microwave signal from the first object towards the second object, causing said second object to receive said signal and re-transmit a signal which is caused to be received by the first object, characterized in that the first object comprises a transmitter/receiver unit (S/M-unit) which is caused to transmit said signal at a frequency f_o from a transmitter antenna; in that the second object (T) is caused to re-transmit said signal modulated with a signal f_m; in that the first object is caused to receive the re-transmitted signal on at least two antennae (M_1, M_2) placed symmetrically on a respective side of the transmitter antenna (S) and in an antenna plane common with the transmitter antenna (S); and in that the angle (Θ) between said antenna plane and said second object, at least in one dimension, namely in a first plane extending through the transmitter antenna and the two receiver antennae, is determined by a phase comparison or an amplitude comparison respectively of said received signals in dependence of whether the second object (T) is located in the so-called proximity zone of the first object or not, i.e. at a distance which is shorter than a distance of the same order of magnitude as the distance d between the two receiving antennae (M_1, M_2) or not, wherein when the second object (T) is located outside the proximity zone said angle (Θ) is determined by a phase comparison between the signal received on respective receiver antennae (M_1, M_2) subsequent to being mixed with the transmitted signal f_o, where the phase difference ($F_2 - F_1$) between the received signals is determined; and in that said angle (Θ) is determined from the equation

$$\Theta = \arcsin \left[\frac{(F_2 - F_1) \cdot c}{2\pi \cdot f_o \cdot d} \right]$$

where c is the speed of light and d is the distance between the two receiver antennae, by means of a computer unit (31) associated with the S/M-unit.

2. A method according to Claim 1, characterized in that an angle Θ' between said antenna plane and the second object (T) is also determined in a second dimension, namely in a second plane extending at right angles to said first plane, by placing a further two receiver antennae (M_3, M_4) symmetrically on a respective side of the transmitter antenna (S) in said antenna plane and caused to receive said re-transmitted signal in a plane at right angles to said firstmentioned plane; and in that the phase difference ($F_4 - F_3$) between the signals received by the further antennae (M_3, M_4) is determined, whereafter the angle Θ' is determined by means of said expression into which $F_4 - F_3$ is inserted instead of $F_2 - F_1$, and where d signifies the distance between the further two receiver antennae.

3. A method according to Claim 1 or Claim 2, characterized in that the computer unit (31) associated with the S/M-unit is caused to calculate whether or not the second object (T) is located in the so-called proximity zone of the first object (S/M-unit), by establishing whether the following two expressions relating to measurement in one dimension

$$\log \frac{G_5}{(G_1 \cdot G_2)^{1/2}} < k_{10} \qquad (16)$$

and

$$k_{11} \cdot G_5 < \max (G_1, G_2) \qquad (17)$$

or the following two expressions relating to measurement in two dimensions

$$\log \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}} < k_5 \qquad (14)$$

and

$$k_6 \cdot G_5 < \max (G_1, G_2, G_3, G_4) \qquad (15)$$

are fulfilled or not,

where G_1 and G_2 are the amplitudes of the respective signals received by the firstmentioned two receiver antennae (M_1, M_2), and where G_3 and G_4 are the amplitudes of respective signals received on said two further receiver antennae (M_3, M_4), and where G_5 is the amplitude of the signal received by said transmitter antenna (S) which is caused to receive signals through a receiver antenna (M_5), and where k_{10}, k_{11}, k_5 and k_6 are pre-determined constants; and in that the second object (T) is considered to be located in said proximity zone when none of the expressions (16) and (17) is fulfilled with respect to one dimension, and when none of the expression (14) and (15) is fulfilled with respect to two dimensions.

4. A method according to Claim 3, characterized in that when said second object (T) is shown by said expression to be located in the proximity zone, said angles Θ, Θ' are determined by amplitude comparison effected by the computer unit (31) from the expressions

$$\Theta = k_7 \cdot \log \left(\frac{G_2}{G_1}\right)$$

$$\Theta' = k_8 \cdot \log \left(\frac{G_3}{G_4}\right)$$

where k_7 and k_8 are pre-determined constants.

5. A method according to Claim 3 or 4, characterized in that when it is established through said expression that said second object is located in the proximity zone, the magnitude R is determined by the computer unit (31) from the equation

$$R = \frac{G_5}{(G_1 \cdot G_2)^{1/2}}$$

in that case when measurement is effected in one dimension, or from the equation

$$R = \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}}$$

in that case when measurement is effected in two dimensions, where R is a measurement of the distance Z between the first object and the second object.

6. Apparatus for determining a mutual position between two objects, comprising a first object provided with a transmitter/receiver unit (S/M) adapted to transmit a microwave signal to the second object (T), said second object being adapted to receive a signal and re-transmit a signal which is arranged to be received by the transmitter/transmitter unit (S/M), characterized in that the transmitter/receiver unit (S/M is adapted to transmit a signal of frequency f_o from a transmitter antenna (S); in that the second object (T) is adapted to re-transmit said signal modulated with a signal f_m; in that the transmitter/receiver unit is provided with at least two receiver antennae (M_1,M_2) for receiving the re-transmitted signal, said receiver antennae (M_1, M_2) being placed symmetrically on a respective side of the transmitter antenna (S) and in an antenna plane common with the transmitter unit (S); and in that the S/M-unit incorporates mixers (9,11; 17,18) arranged to mix the signal received from respective receiver antennae (M_1, M_2) with the transmitted signal f_o, and include phase-comparison circuits (32,33) arranged to compare the phase position of respective received signals in relation to the phase of the transmitted signal; and in that a computer unit (31) is provided for calculating the phase difference (F_2 - F_1) between the received signals and adapted to calculate the angle Θ between said antenna plane and said second object (T), at least in one dimension, namely a first plane extending through the transmitter antenna (S) and the two receiver antennae (M_1, M_2) from the relationship

$$\Theta = \arcsin\left[\frac{(F_2 - F_1) \cdot c}{2\pi \cdot f_o \cdot d}\right]$$

where c is the speed of light and d is the distance between the two receiver antennae M_1, M_2.

7. Apparatus according to Claim 6, characterized in that there are provided two further receiver antennae (M_3, M_4) which are placed symmetrically on a respective side of the transmitter antennae (S) in said antenna plane and in a second plane extending at right angles to said first plane and which are arranged to receive said re-transmitted signal; in that there are provided a further two mixers (19,20) and a further two phase-comparison circuits (34,35) arranged in the manner disclosed in Claim 6; and in that the computer unit is also arranged to calculate the angle θ' between said antenna plane and said second object in a second dimension, namely in said second plane, from the aforementioned expression, where the phase difference $F_4 - F_3$ occurring between the two further receiver antennae (M_3, M_4) is inserted instead of $F_2 - F_1$, and where d indicates the distance between the further two receiver antennae (M_3, M_4).

8. Apparatus according to Claim 6 or Claim 7, characterized in that the transmitter/receiver unit (S/M) is also arranged to measure the amplitude of respective received signals by means of circuits (26,27,28,29,30) incorporating rectifiers; in that the transmitter antenna (S) is also arranged to receive, through a receiver antenna (M_5) the signal re-transmitted by the second object (T); and in that the computer unit (31) is arranged to calculate whether or not the second object (T) is located in the so-called proximity zone of the first object (S/M), i.e. at a distance closer than a distance of the same order of magnitude as said distance d or not, by establishing by calculation whether the following two expressions relating to measurement in one dimension

$$\log \frac{G_5}{(G_1 \cdot G_2)^{1/2}} < k_{10} \qquad (16)$$

or

$$k_{11} \cdot G_5 < \max (G_1, G_2) \qquad (17)$$

or the following two expressions relating to measurements

in two dimensions

$$\log \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}} < k_5 \qquad (14)$$

or

$$k_6 \cdot G_5 < \max (G_1, G_2, G_3, G_4) \qquad (15)$$

are fulfilled or not where G_1 and G_2 respectively are the amplitudes measured by said circuit (26,27) of a signal received by the two firstmentioned respective receiver antennae (M_1, M_2), where G_3 and G_4 respectively are amplitudes measured by said circuits (28,29) of a signal received by the two further respective receiver antennae (M_3, M_4), and where G_5 is the amplitude of a received signal measured by said circuit (30) at the receiver antenna M_5 of the transmitter antenna, and where k_{10}, k_{11}, k_5 and k_6 are pre-determined constants inserted into the computer unit, the second object (T) being considered to be located in the proximity zone when none of the expressions (16) and (17) with respect to one dimension or when none of the expressions (14) and (15) with respect to two dimensions is fulfilled.

9. Apparatus according to Claim 8, characterized in that, when the second object (T) is located in the proximity zone, the computer unit is programmed to calculate said angles θ, θ' from the expressions

$$\theta = k_7 \cdot \log \left(\frac{G_2}{G_1}\right)$$

$$\theta' = k_8 \cdot \log \left(\frac{G_3}{G_4}\right)$$

where k_7 and k_8 are pre-determined constants.

10. Apparatus according to Claim 8 or Claim 9, characterized in that when the second object (T) is located in the proximity zone, the computer unit (31) is programmed to calculate the magnitude R from the equation

$$R = \frac{G_5}{(G_1 \cdot G_2)^{1/2}}$$

when measurement in one dimension is concerned, and from the equation

$$R = \frac{G_5}{(G_1 \cdot G_2 \cdot G_3 \cdot G_4)^{1/4}}$$

when measurement in two dimensions is concerned, where R is a measurement of the distance Z between the first object and the second object.

Fig 1

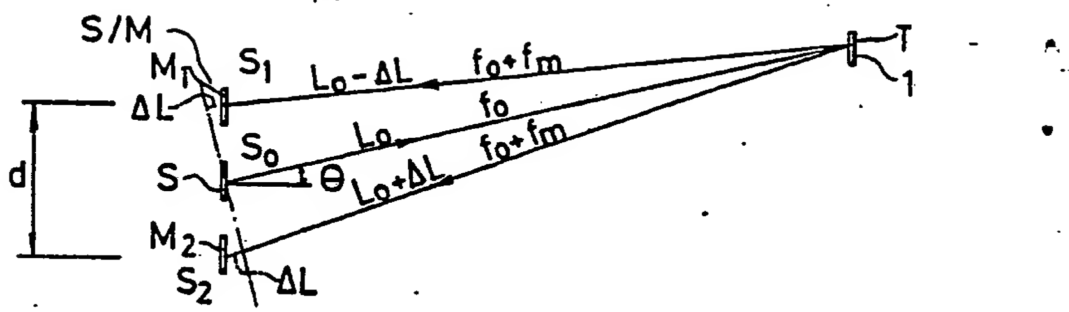


Fig 2

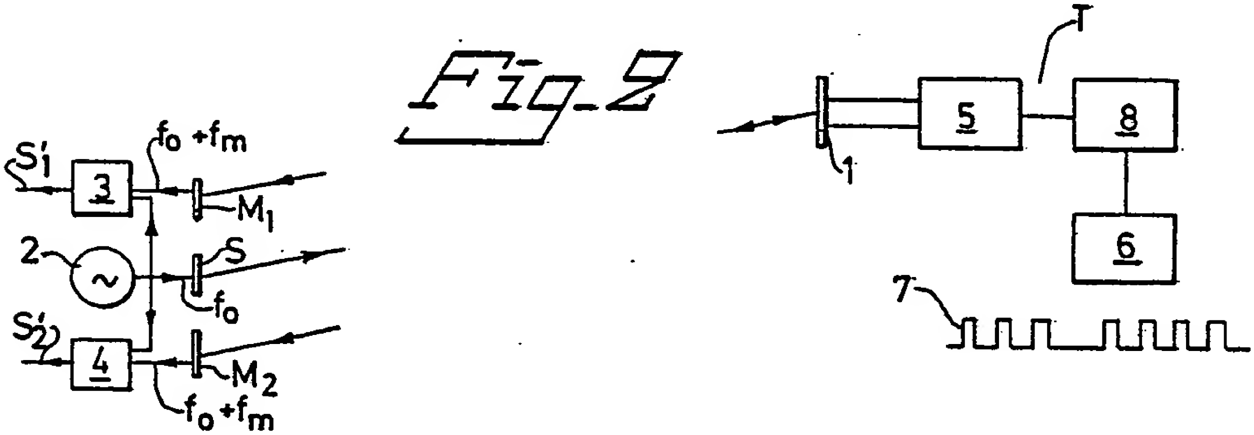


Fig 3

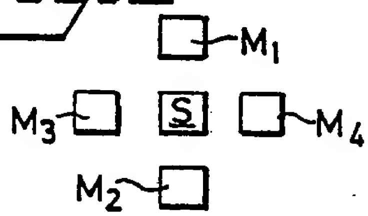


Fig 4

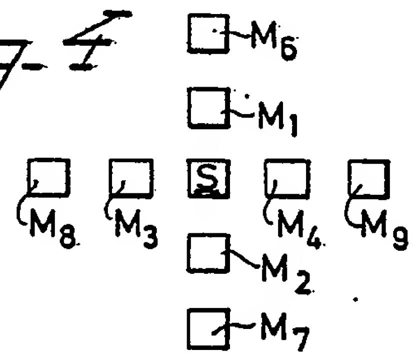


Fig 5

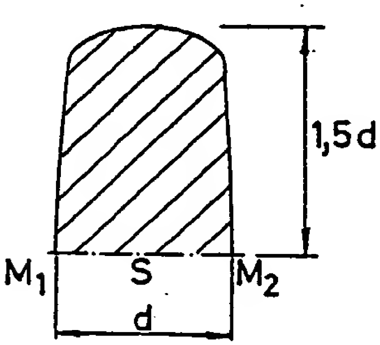


Fig 6

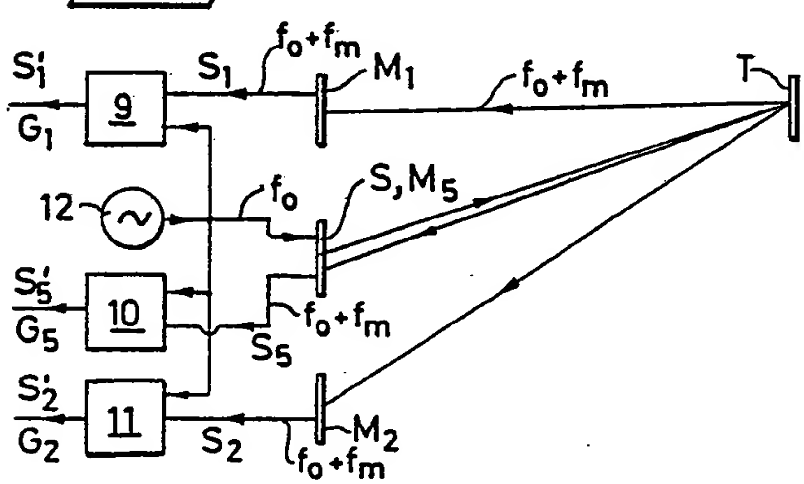


Fig. 7

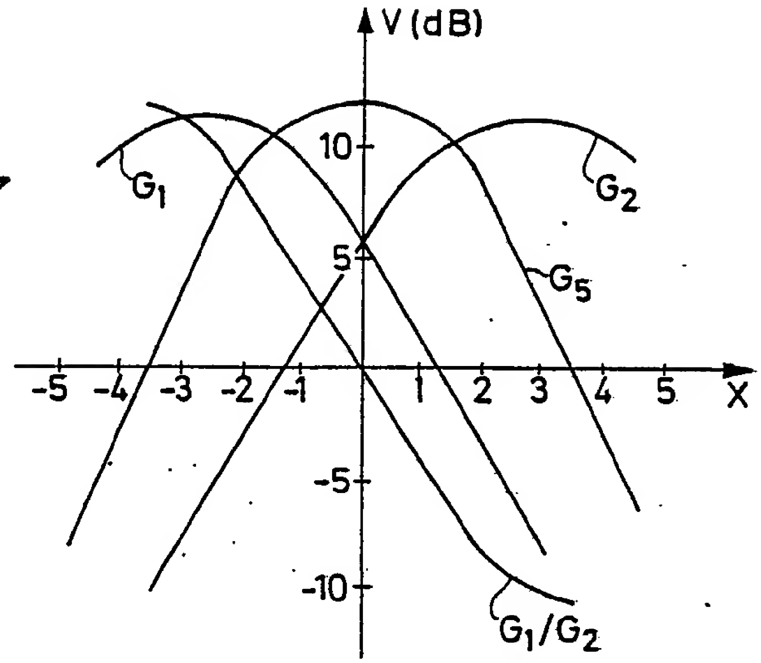


Fig. 8

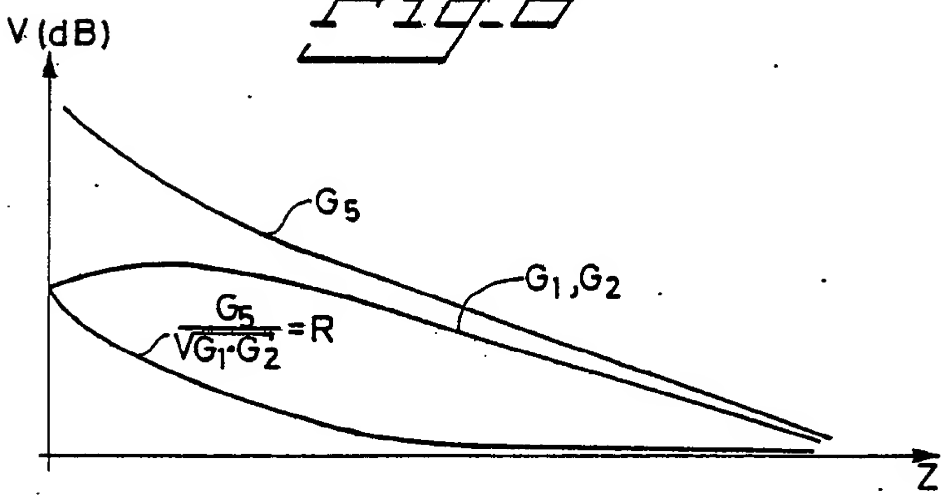


Fig. 9

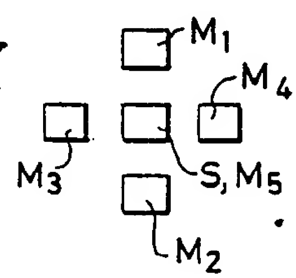


Fig. 10

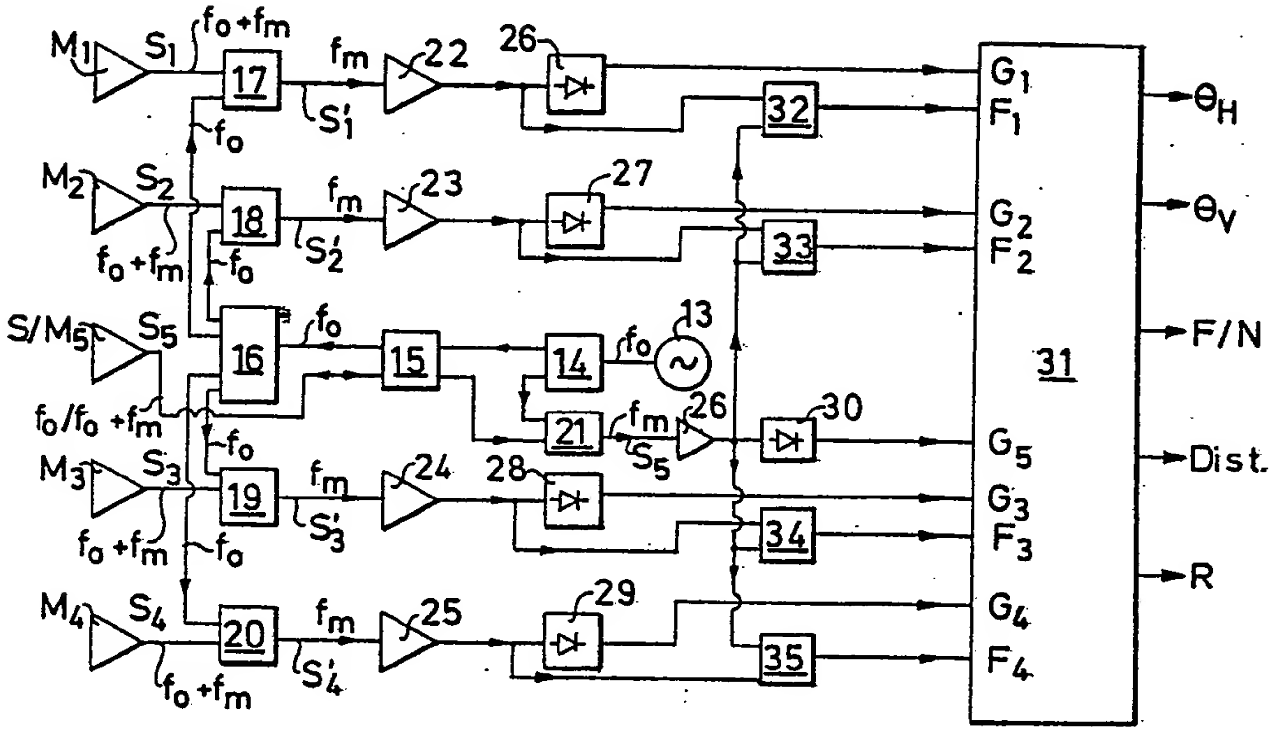


Fig. 11

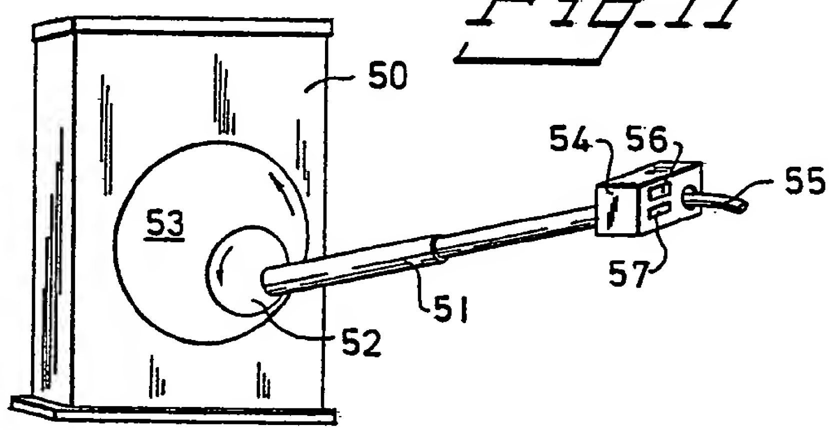
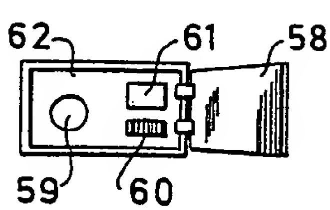


Fig. 12



INTERNATIONAL SEARCH REPORT

International Application No PCT/SE85/00263

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC 4

G 01 S 13/74

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	G 01 S 9/56, /58, 13/42-/48, /74-/84
US Cl	343:6.5, 6.8, 16

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4 151 525 (R. STRAUCH ET AL) 24 April 1979	
A	DE, A1, 3 115 678 (NAAMLOZE VENNOOTSCHAP PHILIPS' GLOEILAMPENFABRIEKEN) 21 January 1982	

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
1985-09-04	1985-09-09
International Searching Authority	**Signature of Authorized Officer**
Swedish Patent Office	Göran Magnusson Göran Magnusson